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IMPACTS OF MATERIAL SUBSTITUTION IN AUTOMOBILE MANUFACTURE ON RESOURCE RECOVERY. VOL. IV APP: H - J

C. O. Lawrence
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16. ABSTRACT

Probable changes in the mix of materials used to manufacture automobiles were examined to determine if economic or technical problems in recycling could arise such that the "abandoned automobile problem" would be resurrected. Future trends in materials composition of the automobile were quantified, and possible constraints related to material characteristics, availability, and price were examined. The automobile resource recovery industry was studied in terms of economic incentives for recycling and technical obstacles to recycling of deregistered automobiles. A macro-model of the economy, the EPA sponsored SEAS model, was used to study overall economic and environmental effects and to bring to light any secondary effects that might be important.

This volume contains appendices covering the following subjects:

1) Shredder Industry Survey
2) Material Substitution and Automobile Performance
3) Integrated Analysis of the Impact of Automobile Composition Changes Using the Strategic Environmental Assessment System.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Materials Recovery - Reclamation, Salvage, Separation. Materials Replacement - Substitutes. Automobiles.		13B

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APPENDIX H

SHREDDER INDUSTRY SURVEY

by W. Henn

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H.1 CAPACITY AND LOCATION OF AUTOMOBILE SHREDDING UNITS

It is estimated that the annual capacity of the automobile shredding industry will reach 9,275,000 tons by the end of 1975. This represents a growth of 16 percent in capability from December 1974 when the capacity is estimated to have been about 8 million tons annually. The marked expansion evidenced in the current year is characteristic of the overall growth experienced by this industry in its 16 year history which began in the early part of the 1960's. This growth history is summarized in Table H1.

The industry capacity is depicted graphically with shredded scrap output (estimated by net domestic purchases and exports) in Figure H1. The two sets of numbers are not strictly comparable due to the existence of shredding units which produce ferrous shredded scrap but, in so doing, do not process automobiles. Two adjustments are suggested: output may be subdivided to reflect automobile shredder output or auto shredder capacity may be adjusted upward to reflect total ferrous shredding capacity. The former alternative is preferred, but it is impossible to execute since no such breakdown of output data is possible. The latter alternative may be accomplished with allowances granted for a rough estimate. A 1970 Institute of Scrap Iron and Steel survey revealed that, of the 97 shredder installations operating at that time, 92 shredded automobiles and 5 processed prompt industrial scrap.[1] In this present attempt to assess auto shredder capacity, three units* shredding obsolete ferrous scrap exclusive of automobile hulks were encountered. It should be noted at this juncture that automobile shredders process more than just automotive scrap, but the ability and propensity to process auto hulks warrants their segregation into this category. It is here estimated that, exclusive of installations processing automobile hulks, 8 to 12 additional units presently shred ferrous scrap, adding about 8 percent to automobile shredder capacity in

---

*Denbo Lipman Co., Pulaski, Tennessee.
Oregon Auto Parts, Oregon, Illinois.
United Auto Disposal Co., Kernersville, N.C. (2nd unit).

TABLE VI

AUTOMOBILE SHREDDER INDUSTRY CAPACITY

Year	Number of Auto Shredding Plants	Estimated Annual Capacity (Thousand tons)	Average Annual Plant Capacity (Thousand tons)
Dec. 1966[1]	25	2,472	98.9
Early 1971[2]	93	5,720	61.5
Jan. 1974[3] (Updated list, See. A)	127	8,000	62.9
Dec. 1975[4] (Updated list, App.A)	146	9,235	63.3

Sources: 1. Steel Magazine, December 1966.

2. Estimate by Adams, An Economic Analysis of the Joint Automobile Problem (Washington D.C. U.S. Government Printing Office, 1972), based on list issued 1/71 by the Institute of Scrap Iron & Steel.

3. & 4. See H.J., Location and Capability of Automobile Shredding Units in U.S., as of December, 1975.

an accounting of total ferrous scrap shredding capability. This 8 percent adjustment is applied year by year over the entire period under examination; the estimate of total shredder capability is indicated by the dashed line in Figure H1. A comparison of this total capacity with output shows that the industry as a whole has been performing substantially below maximum levels. While the estimated capability as of December 1974 was 8.6 million tons, the output that year was 5.1 million tons or 60 percent of capacity. The historical trend of underutilization is displayed in Figure H1. A maximum and minimum estimate of future ferrous scrap output based on projections of demand by domestic and export markets (see Appendix G) is also included in this graph.

The locations of automobile shredders are shown in Figure H2. The States of Vermont, West Virginia, Arkansas, Missouri, Idaho, Montana, Wyoming, North Dakota, South Dakota, Nebraska, Alaska, and Hawaii have no automobile shredders within their borders. This should not be construed to mean that recycling difficulties should be expected in each of these states. More pertinent to this problem are the formulations in Figures H3 and H4. Individual shredder units face transportation costs which permit them to profitably draw auto hulks only up to a certain distance for processing. This distance, typically extending a few hundred miles, depends on a number of factors including the size of plant and prevailing shredded scrap prices. The situations presented by two different average drawing radii are displayed in Figures H3 and H4.

If conditions produced a typical drawing distance of 400 miles, the geographic region where recycling problems (via shredding) would be expected is discerned in Figure H3. The same is done in Figure H4 for a drawing radius of 200 miles. In the case of a 400 mile transportation radius, only the indicated area containing the three-State border of Montana, North Dakota, and South Dakota would fall outside the profitable recycling apron. If the typical profitable drawing radius is 200 miles, portions of Oregon, California, Nevada, Utah, Colorado, Arizona, Idaho, Montana, Wyoming, North Dakota, South Dakota, Nebraska, Minnesota, Texas,

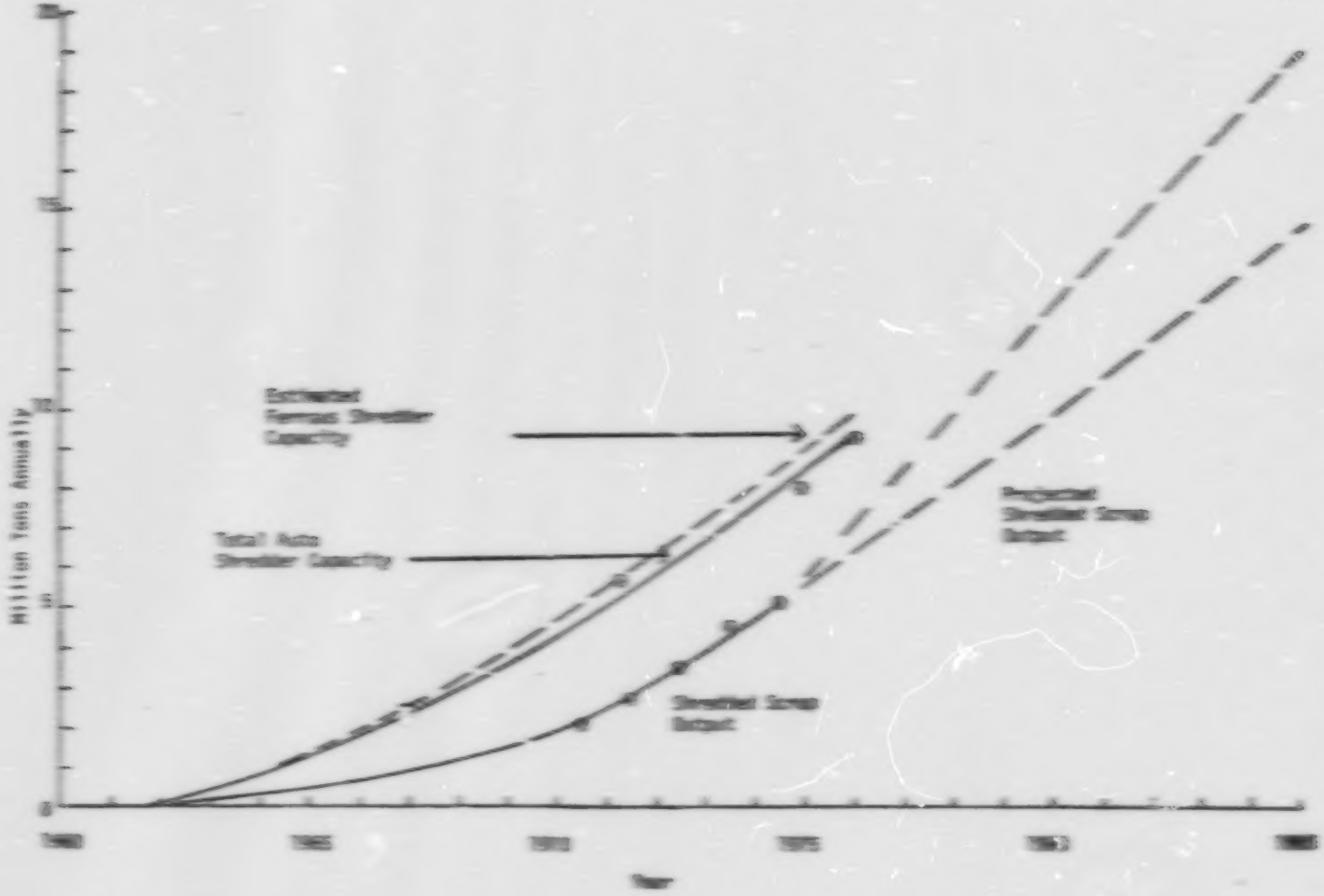

Figure 41: Capacity and Output of Ferrous Shredders

Figure 42: Location of Automobile Shredding Units in the United States

Figure 43: Automobile Recycling Possibilities Via Shredding - 400 Mile Transportation Radius

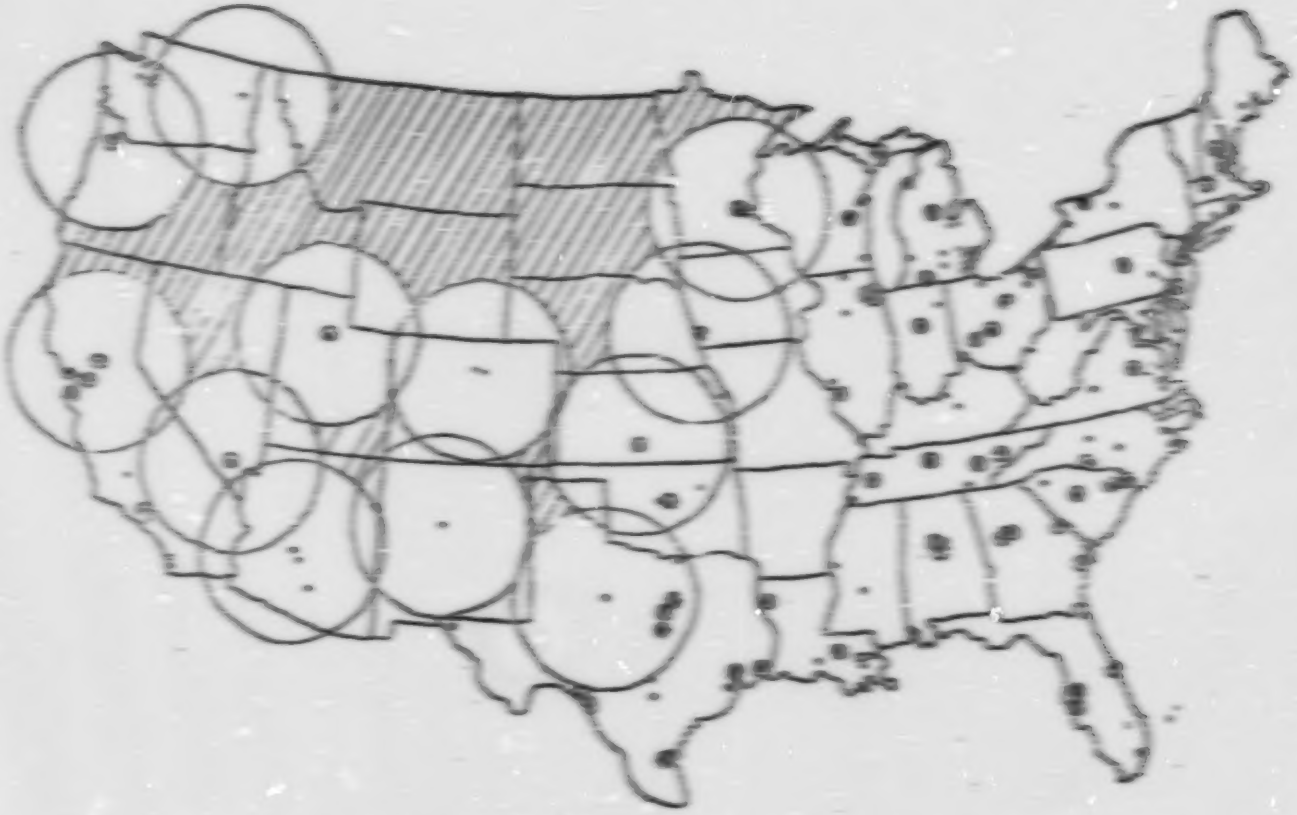

Figure 46: Automobile Recycling Possibilities Via Shredding - 200 Mile Transportation Radius

Oklahoma, and Kansas would fall outside the profitable reach of shredders as indicated in Figure H4. Alaska and Hawaii obviously are not within the radius in either case.

A second method of relating the automobile shredder information to possible recycling problems is to compare capacities with requirements. This is done on a regional basis in Table H2.

The relative comparison for a region is made in the second and third columns where the percentage of total shredding capacity in 1975 and the percentage of automobile registrations in 1973 are presented. Assuming a region's proportion of the deregistration total is roughly the same as its proportion of the registration total, this computation indicates a small relative deficiency of shredding capacity in the Pacific and Mountain regions, and a substantial deficiency in the Middle Atlantic, West North Central, and noncontiguous regions. A recent estimate of the 1975 automotive retirement total (7.576 million)[9] was divided among the regions in the proportions indicated in Column 3. Making the further assumption that each retired auto yields 1700 lbs. of ferrous shredded scrap, the regional availability of retired automobiles is converted to a tonnage figure and presented in Column 4. A comparison of absolute availability and requirements can thus be made between the first and fourth columns. Shortfalls in capacity are exhibited in the Middle Atlantic, West North Central, and noncontiguous regions.

[redacted]

Region	(1) [redacted]	(2) [redacted]	(3) [redacted]	(4) [redacted]
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Column 3: [redacted]

Column 4: [redacted]

Figure 45: Shredding Capability and Recycling Requirement Regions
(Table 42)

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H.3 UNIT MANUFACTURERS

AP American Pulverizer
1249 Macklind Ave.
St. Louis, Mo. 63110

E Eidal International Corp.
Subsidiary of Southwest Factories of Oklahoma City
245 Woodward Ave., S. E.
Albuquerque, N.M. 87102

H Hammermills, Inc.
625 "C" Ave., N.W.
Cedar Rapids, Iowa 52402

J Jeffrey Mfg. Co.
P. O. Box 1379
Columbus, Ohio 42216

L Logemann Bros. Co.
3150 W. Burleigh St.
Milwaukee, Wis. 53210

N Newell Mfg. Co.
P. O. Box 9132
San Antonio, Texas 78204

P Proler International Corp.
7501 Wallacevill e Road, P. O. Box 286
Houston, Texas 77001

WPC Williams Patent Crusher & Pulverizer
2701-23 N. Broadway
St. Louis, Mo. 63102

N/A Not Available

1971(op) Plants operating in 1971 and so indicated on the 1971 ISIS listing.

1971(n) Plants installed in 1971 but not so indicated on 3/71 ISIS listing.

1971(op)* Plants installed before 1971 and operating in that year but not so indicated in the ISIS listing.

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1. Booz-Allen Research, Inc., An Economic Analysis of the Abandoned Automobile Problem (Cincinnati: National Environmental Research Center, 1973).

2. IR&T, Automobile Study for Business International, Scenario I, 1975.

APPENDIX I

MATERIAL SUBSTITUTION AND AUTOMOBILE PERFORMANCE

by R. W. Roig

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MATERIAL SUBSTITUTION AND AUTOMOBILE PERFORMANCE

I.1 INTRODUCTION

Automobile "performance" is an imperfect term for considering topics of importance to this study. "Performance" may conjure up thoughts of speed, acceleration, maneuverability, and other characteristics pertinent to strenuous uses of automobiles. Here, however, we are focusing upon automobiles in their role as personal transport; and the "performance" parameters of concern are reliability, durability, maintainability, economy of operation, comfort and safety in ordinary uses. There probably always will be some small production of cars for "performance" in strenuous use, but material composition of such cars will not be guided by economics or environmental considerations (except as forced by law or Government policy).

Safety considerations were discussed in a previous appendix,* from the standpoint of meeting Federal specifications and crashworthiness of the body and frame. The discussion here in Section I.2 is limited to mechanical requirements for proper day-to-day operation.

Economy of operation is, of course, the reason for the present study, the rationale for changes in automobile materials composition being less weight and hence lower operating costs. This is discussed quite extensively in two earlier appendices.** In section I.3 we give an estimate of average fuel usage (in miles per gallon) of the U.S. automobile fleet in future years based on our projected automobile weights, and some assumptions on future power plant efficiencies. (This estimate is required as an input to SEAS).

---

*R. Rolg, "Safety Aspects of Materials Substitution" Appendix D

**R. Renner, "Future Material Composition in Automobiles," Appendix A
T. Jones, "Energy Consequences," Appendix E

In section I.4 we discuss the matters of reliability and durability as they are affected by material substitution.

I.2 MECHANICAL CONSIDERATIONS

I.2.1 Body, Frames and Running Gear

Body parts are of two types: (1) hang-on parts which function as shields or covers and/or provide cosmetic benefits, and (2) parts which contribute to structural rigidity. Present automobile hang-on parts like hoods, fenders, and trunk lids are formed from mild steels which have yield and tensile strengths comparable to those of common wrought aluminum alloys. Therefore, gauge-for-gauge substitution of aluminum for steel - with a consequent factor of three weight saving (steel to aluminum density ratio is about three) - appears feasible for the nonstructural parts. In load bearing parts, however, account must be taken of the lower modulus of elasticity of aluminum compared to steel. The ratio of steel's modulus of elasticity to aluminum's modulus is about three. However, the actual increase in gauge thickness that would be required in going from steel to aluminum to maintain the same structured rigidity is dependent on the cross-sectional shape of individual members and the degree of redundancy in the structure. However, the full potential weight saving based on a comparison of material density and yield strength will not be realizable in load bearing parts.

Joining aluminum by spot welding, arc welding or with compatible connectors presents problems which also limit the potential weight saving. The lower resistance of aluminum and its propensity to form a protective oxide coating (an advantage in resisting corrosion) makes spot welding more difficult than for steel and requires more expensive equipment and more elaborate techniques. Adhesives in the joint are generally required to bring the strength and fatigue resistance of aluminum spot welds up to the level of spot welds in steel, on a weld-for-weld comparison.

The use of aluminum as a direct substitute for steel in an automobile body is discussed by Glaser and Johnsons [1] and Hsu and Thompson[2] in articles describing the design of an experimental aluminum body to replace a steel body.* Important points gleaned from their articles include:

- Aluminum sheet-metal gauges were generally increased by a factor of 1.4 over corresponding steel gauges to meet structural rigidity requirements. This generally resulted in a structure with a greater margin below yield strength for design loadings.
- A wrought aluminum alloy, designated 2036, having yield and ultimate strength comparable to mild (1010) steel was used.**
- For aluminum gauges 40% greater than steel gauges, spot welds required supplementary adhesive bonding to yield strength and fatigue resistance comparable to spot welds in steel.
- Aluminum spot welds required use of D.C. equipment as against simpler A.C. equipment normally used for spot welding steel.
- The finished aluminum body, which was a direct copy of the steel body in form and structure had a weight about 39% less than the steel body. The authors believe this could be improved for an optimized aluminum design.
- Corrosion resistance of the 2036 aluminum alloy was much better than the 1010 steel it replaced. After 1000 hours in 5% salt spray, 1010 steel showed a corrosion rate of 41.5 mills per year and a 37% loss in tensil strengtn compared to 2.5 mils per year and 2.8% respectively for 2036-14 aluminum alloy. Painted and scored test panels of aluminum showed little deterioration compared to steel panels in another test.

Galvanic corrosion at points where steel and aluminum are jointed can occur with aluminum undergoing the more severe attack.

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*The steel body was itself a proposed replacement for the Cornette Fiberglass body.

**For composition, see forthcoming working paper on secondary aluminum industry. For mechanical characteristics, see Appendix D, "Safety Aspects of Materials Substitution," by R. W. Reig.

Coating the surfaces and designing to avoid inclusions where electrolyte can be trapped can avoid the problem. However, maintaining the integrity of such coatings over a long service life may be difficult.

With respect to plastics, it seems that use will be limited to nonstructural applications. Elastomers may find application in those nonstructural body parts which are susceptible to denting; e.g., fenders and frontal areas. Decorative and lightly stressed functional parts of bodies (trim, door handles, window cranks etc.) are obvious candidates for plastic use because they can be given bright finishes, do not cause galvanic corrosion, and save weight over the usual zinc alloys.

Selective substitution of aluminum (or even magnesium or other light metals) for steel in wheels, brake components, suspensions, drive linkages, etc. is quite possible again with due allowance for the lower elastic modules of aluminum. Component weight savings in the 40% to 60% category are probable, depending on structural rigidity required in a particular part. Control of galvanic corrosion will probably be an important factor, generating a preference for complete one time conversion of an assembly from steel to aluminum rather than a component by component conversion over a period of years. It is hard to envision some parts, such as springs, ever being made of any material but steel. Use of plastics as a substitute of steel in running gear components seems rather a remote possibility except for things like covers and shields. Even here, the maximum operating temperatures will have to be below 300° F for any plastics applications.

I.2.2 Engines

Aluminum use in engines is already rather extensive in parts like pistons, valve covers and carburetors. The major potential for significant weight savings would be for use of cast aluminum blocks.

Aluminum blocks are not particularly new, having been used by various manufacturers at various times including the 1903 Napier, the 1930 V-16 Marmon, and several General Motors, Chrysler and American Motors cars of the early 1960s. Recently, Chevrolet Vegas and Pontiac Astres have featured a new G. M. engine with an aluminum block.

The major drawback of aluminum for use in engine blocks has always been the inferior wear characteristics of aluminum cylinder walls compared to cast iron. This is related to the relative hardness of the materials, gray cast iron having a factor of 2 higher hardness in Brinell hardness tests* than the high silicon (9-10%) aluminum casting alloys (e.g., F 132) commonly used for engine pistons.[3] Until the advent of the Vega engine, the remedy for the wear problem has been to use cast iron inserts for the cylinder walls. Without a strong incentive to decrease weight, the increased costs and added manufacturing complexity associated with inserts caused them to disappear from the marketplace. Possible problems with inserts include differential expansion of aluminum and iron with changing temperatures, galvanic corrosion, and uneven heat conduction across the iron-aluminum boundary. No evidence of a possible return to the aluminum block with iron-insert construction has appeared recently.

The General Motors Vega engine is a radical departure from past practice in aluminum block design. The alloy used (No. 390) has a silicon content of 16% - 18%. The cylinder walls are chemically etched to cause a slight recession of the aluminum relative to the silicon inclusions. The wear surface thus is primarily silicon, the

*The Brinell hardness is measured by pressing a carbide ball into the material surface. It is equal to the applied load in kilograms divided by the area of the resulting indentation in square millimeters. According to the Metals Handbook,[3] F-132 alloy has a Brinell hardness of 105 when tested with a 10 mm diameter ball and a 500 kg. load while gray cast iron as used in a typical automotive block (3.25% carbon with other alloy elements) is claimed to have a hardness in the cylinder wall of 170 to 229. The test conditions for the iron hardness determination are not given but are probably a 10 mm diameter ball and a 3000 kg. load.

hardness of silicon being comparable to that of iron.[7] (While not a difficult operation in a production shop, the chemical-etching steps will present serious problems to engine reconditioners.)

The Vega engine received some bad publicity in its early history and is still under a cloud of suspicion, as witness the following quote from Consumer Reports:

" . . . the aluminum four cylinder engine, . . .; has shown a strong tendency to self-destruct after a couple of years of operation."

Recently General Motors has offered a 60,000 mile warranty on the engine, undoubtedly to counter such strong criticisms. The basic problem appears to be that the aluminum block is very sensitive to overheating. Operation while overheated causes rapid deterioration of cylinder walls and permanent damage. GM's solution is to attempt to insure that overheating will not occur by installation of a radiator overflow tank and a coolant low-level warning light. While not ready to give up on its aluminum engine, G.M. is evidently taking a cautious approach to extending its use. Note that its new subcompact, the Chevette, is being brought out with an iron engine-block.

Cylinder heads are another major candidate for fabrication of aluminum and in some instances are already being so made. However, valve seat inserts of steel are required to obtain sufficient hardness at high temperatures. High stress parts, such as connecting rods and crank-shafts, are possibilities but possible weight savings are less by reason of the rigidity and strength requirements of these parts.

Other parts of the power train, notably automatic transmission housings are already being made of aluminum castings. Despite higher material costs, aluminum castings are often less costly than iron castings because the casting can be made more precisely with less scrap

[7] Consumer Reports, May 1975, p 302 - report on the Pontiac Astre.

generation, and fewer subsequent machine operations. Again, high stress parts where surface wear characteristics are important; e.g., gears and drive shafts, present less opportunity for weight savings relative to steel.

Use of plastics in engines will remain relatively minor, due largely to the high temperatures of operation that must be accommodated. Some plastics have been used in low stress applications, such as timing gears.

While our stress in the present study has been on aluminum as a substitute for steel, the possibilities for magnesium, especially in engines and transmission, should not be overlooked. Magnesium has two thirds the density of aluminum, and is stronger and harder to boot.[3] Volkswagen and Porsche use magnesium for the crankcases of their air-cooled engines and claim to be able to produce these castings more cheaply in magnesium than aluminum due to better casting characteristics. The present production of magnesium in the U.S. is, however, only a fraction (3%) of aluminum production. Price of magnesium in 1974 ranged from 120% to 220% than that of aluminum.[4]

I.3 AVERAGE FUEL USAGE OF THE U.S. AUTO FLEET IN FUTURE YEARS

The performance parameter that, in a sense, instigated this study is fuel economy - the well known fact that reduced car weight can lead to increased average miles per gallon. There are, of course, many influences on the fuel economy of a car, of which weight is only one. Fuel economy in urban area driving, where many accelerations and decelerations occur, should be particularly sensitive to car weight. Open highway driving at constant speed should show a smaller coupling between car weight and fuel economy, but not complete independence because larger cars should tend to have slightly greater rolling resistance and larger frontal area for air resistance. Generalizing is, however, extremely difficult because differences in car design,

equipment, manner of driving, and condition can easily cause differences in fuel economy which swamp effects from differences in weight in any particular comparison.

To quantify average effects attributable to automobile weight, we can refer to Fig. II (also appears as Fig. A4 of Appendix A and Fig. E1 of Appendix E) which is extracted from the joint DOT and EPA report to Congress on fuel economy.[6]* This shows fuel economy versus weight for cars driven over the EPA composite cycle. Obviously it is an "on-the-average" or curve fit model. The several parallel curves represent changes in autos other than weight reduction; e.g., reduction in aerodynamics drag, change to radial tires to reduce rolling friction, changes in engines to increase efficiency. Over the range of weights shown the curves can be approximated by a section of an hyperbola:

$$FE = \text{fuel economy in miles per gallon} = \frac{K W_b}{W}$$

W = car weight in pounds

W_b = a reference weight.

The appropriate value for K for 1974 cars, when new, would be 11 mpg if W_b were taken as 5000 lbs, from Fig. II.

In any particular year the inventory of cars in use consists of cars made in many model years and the average fuel economy calculation must be an average over all cars in the inventory. Thus, values of K must be available for each model year and an average W must be selected for each model year. A model for fuel economy should include adjustments in K for increases or decreases in engine efficiency and other technical changes (e.g., radial tires) and an allowance for the

*Rennur, R., "Future Materials Composition in Automobiles"
Jones, T., "Energy Consequences"

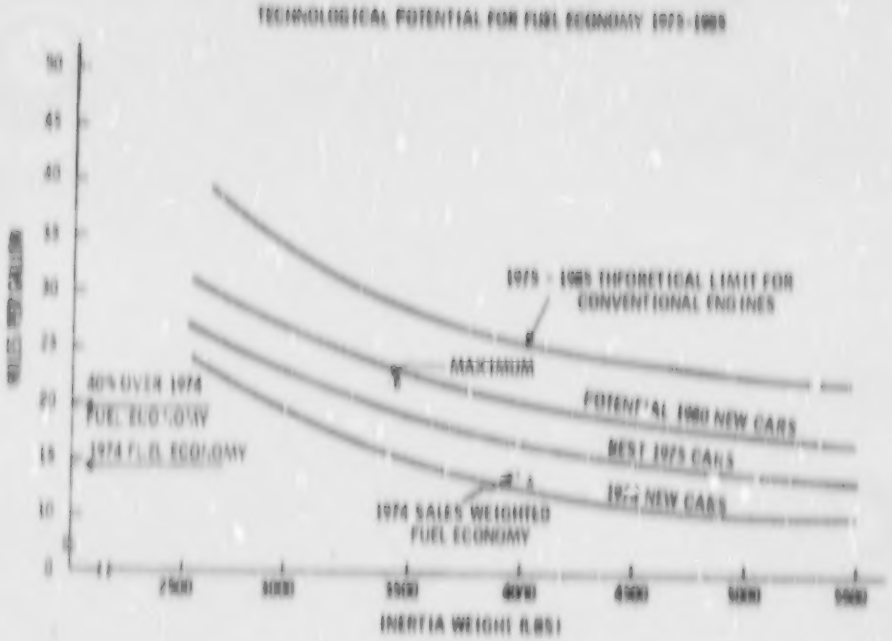

Figure II. 1975 - 1985 Technological Potential for Fuel Economy from EPA-DOT Fuel Economy Study

fact that as cars get older, their engines become less efficient. Also, older cars may be fitted with cheaper, bias-ply tires. There does not appear to be any rigorous way to develop such a model, so we present the following as a hypothesis based on judgment, discussions with others, reasonableness, and necessity:

$$FE(Y_1, Y_2) = \frac{F_b W_b}{W(Y_2)} \left| 1 + a\left|Y_2 - Y_b\right| - b\left(Y_1 - Y_2\right)\right|$$

$FE(Y_1, Y_2)$ = average fuel economy in year Y_1 of cars manufactured in year Y_2

$W(Y_2)$ = average weight of cars manufactured in year Y_2

Y_b = a base year

F_b = a base year fuel economy factor

a = efficiency increase factor

b = efficiency decrease factor due to aging.

The values of $W(Y_2)$ for Y_2 = 1975, 1980 and 1990 are taken as those for the sales weighted composite cars (most likely materials composition) from Renner, Appendix A. Weights on earlier years are not readily available and were estimated as 3,750 lbs for 1973 and earlier. Weights for intervening years are taken as linear interpolations, while average car weight for years after 1990 is assumed to be constant at the 1990 value. This gives an average car weight versus year of manufacture curve shown in Fig. 12.

The base year Y_b was chosen as 1973. The efficiency improvement factor was chosen arbitrarily as 0.01; i.e., 1% improvement per year or 22% by 1995 on the base year of 1973. The aging factor b was chosen at 0.005 or 0.5% per year, again rather arbitrarily. The absolute value of the difference between year of manufacturer, Y_2, and the base year Y_b was used as the multiplier for a, as a crude attempt to account for the fact that engine efficiency had been decreasing up to 1973 to meet pollution abatement standards. Introduction of catalytic converters in some exhaust systems starting in 1974 should have been reflected in a slight increase in engine efficiency in 1974

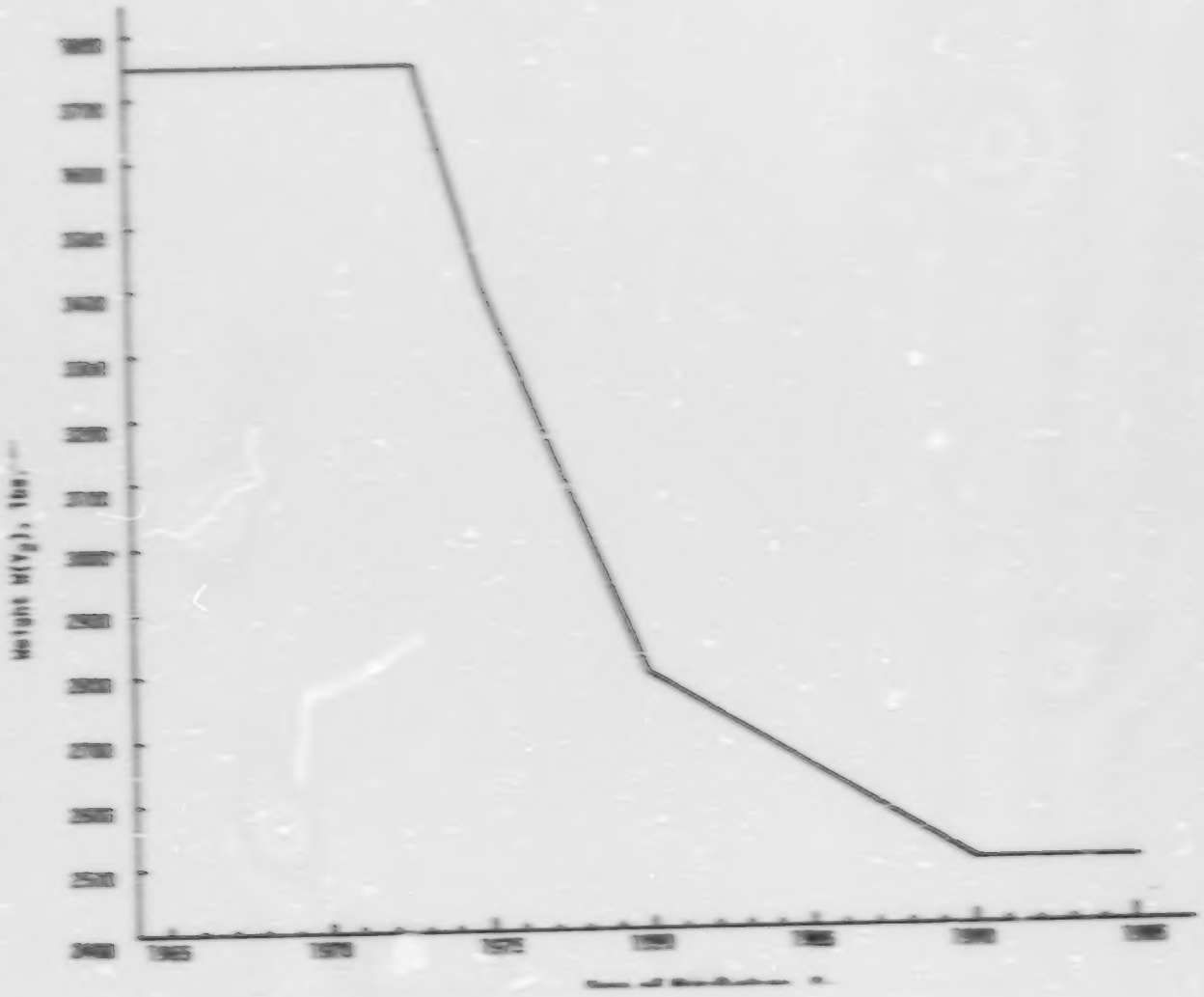

Figure 12. Assumed Average Weight of Cars vs. Year of Manufacture

over 1973. The base year fuel economy factor, F_b, and base weight, W_b, were used as free parameters to match the model to historical fuel economy data, averaged over all cars in inventory. The values ultimately chosen were F_b = 13.5 mpg, and W_b = 3,650 lbs. This F_b value is just slightly less than the ordinate for 1974 cars at 3,650 lbs. weight in Fig.11.

The averaging over the inventory of cars in use should be given by:

$$FE(Y_1) = \left[\frac{\sum_{Y_2 \leq Y_1} FE^{-1}(Y_1, Y_2)\, N(Y_1, Y_2)\, M(Y_1, Y_2)}{\sum_{Y_2 \leq Y_1} N(Y_1, Y_2)\, M(Y_1, Y_2)} \right]^{-1}$$

where

$N(Y_1, Y_2)$ = number of cars manufactured in year Y_2 that are in use in year Y_1.

$M(Y_1, Y_2)$ = average number of miles driven in year Y_1 by cars manufactured in year Y_2.

To simplify the calculations (and in view of the many approximations and assumptions involved, an elaborate calculation is hardly justifiable) we assumed that $M(Y_1, Y_2)$ = a constant, that $N(Y_1, Y_2)$ is equal to the number of cars sold in year Y_2 for $(Y_1 - Y_2) \leq 9$ and zero for $(Y_1 - Y_2) > 9$ and that the arithmetic mean is a close enough approximation to the harmonic mean implied in the above equation for $FE(Y_1)$. Then,

$$FE(Y) \approx \frac{\sum_{k=0}^{9} FE(Y, Y-k)\, N_0(Y-k)}{\sum_{k=0}^{9} N_0(Y-k)}$$

where $N_0(Y)$ = number of cars sold in year Y and $N_0(Y)$ is taken from

a recent study by IR&T for Business International.[8] The value for N_0 (Y) is shown in Fig. I3. Values prior to 1974 are actual sales while subsequent values are projections. Computed values for $\overline{FE}(Y)$ are shown in Fig. I4. (Actually only values for 1971, 1973 and 1975, 1977, 1980, 1985, 1990 and 1995 were computed while intervening years were linearly interpretated.) Also shown are historical values taken from the EPA-DOT report to Congress on fuel economy.[5]

I.4 RELIABILITY AND DURABILITY

Consideration of reliability and durability are probably responsible for the very conservative image projected by engineers in general and automobile engineers in particular. They are reluctant to substitute a new mechanism, or a new material for a tried and proven one because differences which are obscure at the design stage, or which do not produce difficulties in accelerated proof-tests, can sometimes cause defective operation after some period of actual use. These can result in expensive recalls of large numbers of cars for repairs several years after the cars have been manufactured.

An often heard assertion (at least often heard by the author in the course of this study) is that use of aluminum will increase automobile life by decreasing corrosion, particularly of body parts. As noted in section I.2 of this paper, tests of panels in salt spray show that aluminum fares much better than steel. In one test cited by Hsu and Thompson[2] a panel of 2036 aluminum alloy was jointed to a panel of 1010 steel and the combination subjected to immersion in sea water and acetic acid for one week. By use of sealants and protective coatings, the aluminum had been preserved from corrosion at the interface while the steel had corroded. However, the effectiveness of protective coatings when the joint is continually flexed and strained over a period of years is not established by such a short immersion test.

Since aluminum has a much higher oxidation potential than iron, the result of having aluminum and iron or steel in direct contact with each other and with an electrolyte, such as a salt solution, will be galvanic corrosion of the aluminum. The iron will corrode less than

Figure 13: New Car Registrations (1955-1985)

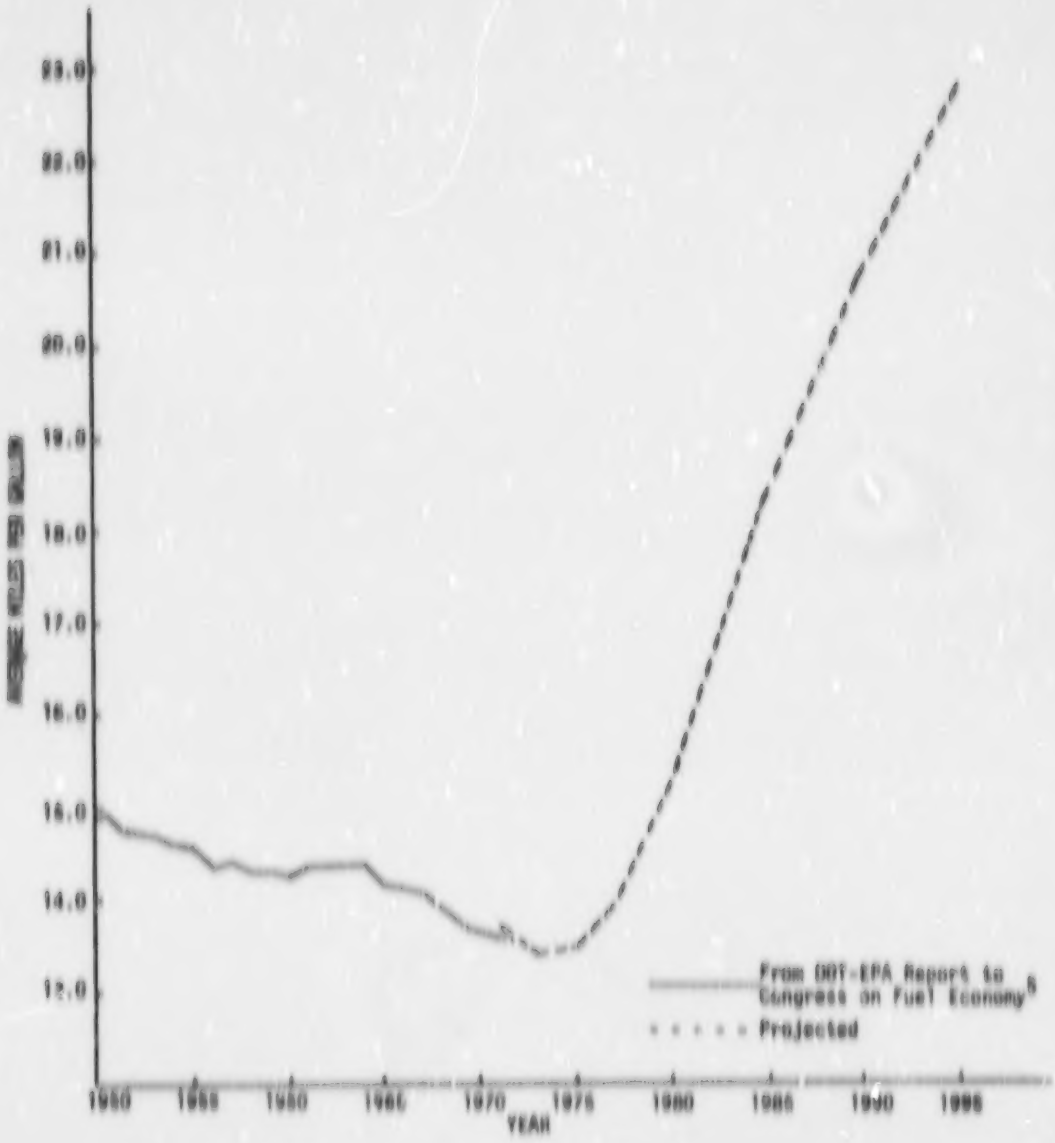

Figure 14: Average Fuel Economy of U.S. Passenger Car Fleet 1950-1995

if the aluminum were absent. Insulating the iron from the aluminum, using a paint or other nonconducting coating in the steel-aluminum joint, will stop the galvanic action, and the iron will corrode at whatever rate it would in the absence of the aluminum. A conducting path through bolts or other fasteners will negate the effect of the protective coating. If the steel-aluminum joint is subjected to flexures during normal use, it is possible that the metal-to-metal contacts will result from rubbing action either at the interface or at the fasteners. Establishment of an electrical conducting path through the interface will allow localized galvanic corrosion of the aluminum to begin.

Alloying elements can effect galvanic corrosion. Thus stainless steels are known to promote galvanic corrosion of ordinary mild steel. Of the two principal alloying metals in stainless steel, chromium has a higher oxidation potential than iron, while nickel has a lower oxidation potential than iron. If aluminum (or magnesium, which has an even higher oxidation potential than aluminum) is interposed in the steel-stainless steel circuit, the aluminum which has a higher oxidation potential than chromium, iron or nickel will be corroded while both steels are preserved until the aluminum is gone. Aluminum has sometimes been used as a "sacrificial" metal in this way.

The assertion that increased use of aluminum will tend to increase automobile longevity thus needs to be carefully examined and qualified. If, for instance, aluminum fenders are used in a "hang-on" mode of construction, while the basic body is made of steel, the expected longevity of the fender will depend, in part, on the effectiveness of the protective coatings and sealants used between the steel body and the aluminum fender, as well as the bushings and washers used to isolate the connectors from direct metallic contact. If the entire body is aluminum, then the potential galvanic corrosion problem occurs at the attachment point to the steel frame. For a unitized body and frame of all aluminum construction, the number of exposed dissimilar metal joints should be small and potential corrosion problem less than for either of the aforementioned types of construction.

The longevity of cars with increased aluminum composition will thus depend strongly on their type of construction and the care taken in their design and manufacture. Sealing and protecting bi-metallic joints in a way that will not deteriorate with use is likely to be expensive and require tight quality controls. Poor design or sloppy manufacturing practices could lead to a decreased life expectancy for automobiles with increased aluminum content.

Plastics do not, of course, have any corrosion problems and may for this reason, be favored for nonstructural hang-on parts. There is, in fact, a certain appeal to the idea of a fender made of an elastomer that will recover its shape after a minor bumping. Not all fenders are nonstructural however, and reinforced plastics, such as fibreglass reinforced polyester, will not have this bounce-back property. In fact, repairs to fibre-glass body parts are generally more expensive than similar repairs to sheet metal.*

The most important limitation to use of plastics will be the temperature of the operating environment. Engine compartment hoods are a case in point, where temperatures can reach 300° F under severe conditions.[2] This is near the upper limit for most plastics and prolonged use at such a temperature is likely to cause some deterioration in the plastic; e.g., warping or cracking due to breaking of some of the internal cross linkages of the polymer chains.

*This is reportedly one reason that GM has contemplated a metal body for its Corvette, either steel or the experimented aluminum body built by Reynolds.

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APPENDIX J

INTEGRATED ANALYSIS OF THE IMPACT OF AUTOMOBILE COMPOSITION CHANGES USING THE STRATEGIC ENVIRONMENTAL ASSESSMENT SYSTEM

by
Marc Narkus-Kramer
Andrea L. Watson

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3.1 Methodology

The Strategic Environmental Assessment System (SEAS) is an extensive input-output economic model, that utilizes pre-existing demographic, economic and technological projections in order to forecast economic and environmental conditions up to 1985. It consists of a set of modules, tied together and each having scenario capability. Critical assumptions involving economics and/or the environment can be input to the SEAS modular system to determine the consequences of various courses of action. The scenarios which were analyzed for this study concerned the impact of materials substitution in automobiles of the future were:

(1) No change in materials composition of the automobile from the 1971 level
(2) Most probable car
(3) Maximum credible aluminum car
(4) Maximum credible plastic car.

The projected cases, (2), (3) and (4), were based on an engineering study by Roy Renner.[1] They reflect the possible options for substitution of aluminum and plastic for iron and steel and copper in the trend toward smaller and lighter vehicles which consume less fuel and materials resources. A base case,(1) above, was run in the model to allow comparison with a no materials substitution scenario.

An economic input-output model, "INFORUM," was used to project economic sector outputs and other econometric impacts. The "A" matrix coefficients, representing material requirements for industrial output in the input-output table were revised to reflect the changes in materials composition of the automobile for the various alternate designs for several years. Each "A" coefficient represents the value of material purchases required per dollar of output of a given industrial sector. In this case, the revised coefficients represented the projected required purchases of ferrous metals, aluminum, plastics, and copper by the automobile industry, for the three

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1) Roy Renner,"Future Material Composition in Automobiles" Appendix A.

cases: most probable, maximum credible aluminum and maximum credible plastic automobile.

The amount of increase (or decrease) from the base case in the material requirements per automobile for 1980 and 1985 was computed based on the estimates made by Roy Renner for each case. This fraction was then used to revise the appropriate "A" coefficients currently in the model. Not only direct sales of materials to the automobile industry were taken into account, but also sales of materials through intermediate industries, i.e., the sales of iron and steel to metal stampings, which produce body fenders for automobiles. Revised coefficients approximated nearly all of the direct and indirect sales of materials to the motor vehicle industry. All other "A" coefficients as projected in the input-output table were left unchanged. Also, projections of total output of the motor vehicle industry made by the model were not changed.

The basic assumption of this methodology is that the flows of materials in dollar value as computed in the input-output model of the US economy are comparable to flows of materials in physical units. The underlying principle is that there is a proportionality between dollar flows and flows of materials throughout the economy. Under this assumption, the input coefficient represents the weight of a material required for the output of an industry. Because the projections in the model are made in constant dollars, it is assumed that the average cost of the automobile and material costs will be the same in the future.

Another assumption made in this methodology was that the material substitutions projected by Renner for the passenger car would be reflected in other vehicles produced by the motor vehicle industry, the sector in the SEAS-INFORUM model for the motor vehicle industry.

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1) Approximately 90% of ferrous metals (iron and steel), 80% of aluminum, 70% of copper and 50% of plastics required by the automobile industry directly or indirectly in the model were taken into account.

motor vehicles and parts, includes the output of passenger cars and assembled trucks, commercial cars and buses.

The second change made in the model was that the average miles per gallon for automobiles projected to be on the road in 1985 was computed to take into account the fuel savings of the smaller and lighter automobiles. The revised miles per gallon figure was applied to the vehicle miles travelled forecast in the SEAS transportation model to obtain an estimate of savings in gasoline consumption. This was reflected in reduced consumer demand for gasoline in the economic model.

Another revision was that any decline in the demand for petroleum from reduced gasoline consumption was to be reflected in decreased imports. This was in accordance with the policy set forth in Project Independence to decrease U.S. dependence on foreign oil.

J.2. Economic Analysis

J.2.1 Introduction

Four scenarios were analysed using the Strategic Environmental Assessment System (SEAS). As discussed in the previous section, the four scenarios involved were:

(1) No change in auto composition from the 1971 level;
(2) Most probable car;
(3) Maximum aluminum car;
(4) Maximum plastic car.

The purpose of running the four scenarios was to determine, on a national level, what economic and environmental impact would result from the changing composition of the automobile. Three models of SEAS were run to perform this analysis: INFORUM (the economic module), RESGEN (the air/water pollution module), and SW/R (solid waste module). The results from each of those modules will be discussed separately.

J.2.2 Economic Analysis (SEAS INFORUM Module)

Our analysis will focus upon the comparison for 1985 of the projections of scenarios (2), (3) and (4) to the base case scenario (1). The first level of analysis involves interpreting the aggregated economic statistics as projected by INFORUM: total employment, civilian unemployment rate, GNP, trade balance, and personal consumption expenditure. Table J1 presents the projected changes in the aggregate economic statistics for 1985. The primary conclusion is that the overall impact on the economy of changes in automobile composition is negligible. This result indicates how diverse the American economy is. A major change in the Nation's largest manufacturing sector creates only a small national economic impact. This result can be explained in part by our assumption that the reduction in the output of steel for use in the automobile is partially compensated for by the

increase in aluminum and plastic production. For example, in the maximum aluminum scenario, aluminum is forecasted to have a 2.7 billion dollar increase in production over the base scenario while steel exhibits a 5.4 billion dollar decrease.

Though the changes in the aggregate statistics are small, they are worth commenting upon since each of the three materials substitution scenarios show change in the same direction from the base scenario. The unemployment rate increases, imports decrease slightly, and all other statistics remain about the same. Unemployment changes can be directly attributed to the decreased employment in the steel and petroleum industries. The petroleum industry exhibits decreases in employment over the base case because lighter cars result in gasoline savings. The unemployment resulting from the secondary impacts of the changing composition of the automobile is surprisingly more significant than the primary impacts. The industries affected by primary impacts include iron and steel manufacturing plus ferrous metal mining, petroleum refining, nonferrous metal mining and production, and plastic production. The economic sectors affected by secondary impacts include the remaining industrial, commercial and agricultural sectors in the economy. Table 32 lists the employment impacts. Employment in the primary industries affected for the maximum aluminum car case decreases 51,060 from the base case. Employment in the remaining industries in the economy decreases by 104,000. Though none of the remaining economic sectors is affected significantly, the total aggregate impact is greater than that of the primary industries.

The reduction in imports can be attributed almost entirely to savings in gasoline resulting from lighter cars. By 1985, the average car on the road would have a gasoline mileage of 18.1 mpg as compared to our base case of 13.3 mpg, thus resulting in a savings of 719×10^6 barrels of oil. At $15 a barrel, this would

TABLE 31

COMPARISON OF AGGREGATED ECONOMIC STATISTICS FOR 1995

Scenario 1: National Economic Model - No Chg in Auto Comp Base Case
Scenario 2: National Economic Model - Most Prob Chg in Auto Comp

Name	Units	S1	S2	$\frac{S2_{95} - S1_{95}}{S1_{95}}$
Total Population	(M)	255.7	255.7	0.0
Total Labor Force	(M)	107.7	107.7	0.0
Total Households	(M)	94.21	94.21	0.0
Total Employment	(M)	103.3	103.1	-0.18
Total Jobs	(M)	107.3	107.1	-0.17
Civilian Unemployment Rate	(%)	4.221	4.395	4.12
Per Capita GNP	($)	7,883	7,848	-0.11
Per Capita Disposable Income	($)	6,198	6,198	0.0
Equipment Investment	(M$)	160,900	160,500	-0.22
Construction Investment	(M$)	130,000	129,500	-0.40
Inventory	(M$)	11,350	11,220	-1.09
Exports	(M$)	124,400	124,000	-0.27
Imports	(M$)	-131,600	-128,150	-2.68
Personal Consumption Expend.	(M$)	1,192,000	1,188,000	-0.34
Defense Spending	(M$)	69,010	69,010	0.0
Non-defense Spending	(M$)	35,050	35,050	0.0
Education	(M$)	81,500	81,500	0.0
State & Local Health, Welfare	(M$)	14,000	14,000	0.0
State & Local Safety	(M$)	3,203	3,203	0.0
State & Local General	(M$)	76,360	76,360	0.0
Public Construction	(M$)	37,180	37,180	0.0

M = Millions
M$ = Million Dollars

TABLE J1 (continued)

SCENARIO COMPARISON FOR INFOPLAN

Scenario 1: National Economic Model - No Chg in Auto Comp Base Case
Scenario S: National Economic Model - Max Credible Alternative

Name	Units	S1	S3	(S3 - S1)/S1 %
Total Population	(M)	235.7	235.7	0.0
Total Labor Force	(M)	107.7	107.7	0.0
Total Households	(M)	84.21	84.21	0.0
Total Employment	(M)	103.1	103.1	-0.19
Total Jobs	(M)	107.3	107.1	-0.18
Civilian Unemployment Rate	(%)	4.221	4.407	4.40
Per Capita GNP	($)	7,853.	7844.	-0.11
Per Capita Disposable Income	($)	4,388.	4388.	0.0
Equipment Investment	(M$)	180,900	180,500	-0.23
Construction Investment	(M$)	130,000	129,400	-0.45
Inventory	(M$)	11,380	11,010	-1.18
Exports	(M$)	124,400	124,000	-0.30
Imports	(M$)	-131,600	-127,700	-2.96
Personal Consumption Expend.	(M$)	1,192,000	1,188,000	-0.38
Defense Spending	(M$)	69,010	69,010	0.0
Non-Defense Spending	(M$)	35,060	35,060	0.0
Education	(M$)	81,500	81,500	0.0
State & Local Health, Welfare	(M$)	14,080	14,080	0.0
State & Local Safety	(M$)	3,203	3,203	0.0
State & Local General	(M$)	76,360	76,360	0.0
Public Construction	(M$)	37,180	37,180	0.0

TABLE 'J1' (continued)

Scenario 1: National Economic Model - No Chg in Auto Comp Base Case
Scenario 4: National Economic Model - Max Credible Plastic

Name	Units	S1	S4	$\frac{S4 - S1}{S1}$ %
Total Population	(M)	235.7	235.7	0.0
Total Labor Force	(M)	107.7	107.7	0.0
Total Households	(M)	84.21	84.21	0.0
Total Employment	(M)	103.3	103.1	-0.16
Total Jobs	(M)	107.3	107.1	-0.15
Civilian Unemployment Rate	(%)	4.221	4.373	3.59
Per Capita GNP	($)	7,651	7646	-0.09
Per Capita Disposable Income	($)	4,388	4388	0.0
Equipment Investment	(M$)	180,900	180,700	-0.13
Construction Investment	(M$)	130,000	129,500	-0.38
Inventory	(M$)	11,390	11,290	-0.88
Exports	(M$)	124,400	124,200	-0.16
Imports	(M$)	-131,600	-127,800	-2.88
Personal Consumption Expend.	(M$)	1,192,000	1,188,000	-0.33
Defense Spending	(M$)	69,010	69,010	0.0
Non-Defense Spending	(M$)	35,060	35,060	0.0
Education	(M$)	81,500	81,500	0.0
State & Local Health, Welfare	(M$)	14,080	14,080	0.0
State & Local Safety	(M$)	3,203	3,203	0.0
State & Local General	(M$)	78,350	78,350	0.0
Public Construction	(M$)	37,180	37,180	0.0

TABLE J2

EMPLOYMENT IMPACTS FOR THE
MAXIMUM ALUMINUM CAR

	81	83	83 - 81
PRIMARY IMPACTED INDUSTRIES			
Steel and Iron	757,500	665,200	- 92,300
Petroleum	206,800	186,000	- 20,800
Non-Ferrous Metals	343,000	389,000	+ 46,000
Plastics	298,000	304,000	+ 6,000
SECONDARY IMPACTED INDUSTRIES	105,660,000	105,556,000	-104,000
	107,260,000	107,100,000	-165,000

result in an import savings of 10.78 billion dollars (1985 dollars).

J.2.3. Economic Impacts on an Industry Level

The INFORUM model as developed by SEAS has 533 sectors of which 185 are part of the I/O model and 348 are part of the INSIDE module which is embedded in the INFORUM package. The INSIDE sectors contain industry information which is in greater detail than those provided by the Input/Output model. These sectors were developed so that pollution outputs could be identified with the appropriate parts of an industry. The INSIDE sectors are so constructed that changes in the economy which are implemented in the I/O model are reflected in the INSIDE equations.

Table J3 lists the significant changes in output which occur in the three scenarios as compared to the base case. The first page of Table J3 lists outputs from the input output part of INFORUM which have output changes from the base case of over 1% (some energy sectors are also exhibited). The following two pages list the INSIDE sectors which have changes of greater than 1% or are relevant to energy and plastic production. Several conclusions can be drawn from analyzing these results. The primary conclusion is that the impacts of changing the composition of the automobile damp out rather quickly and that industries which are more than two steps removed from the automobile industry are not affected enough to change over 1%. This is illustrated in Figure J1 which links the industries listed in Table J3 into a sequence of sales.

Figure J1 is constructed by analyzing the structure of the input/output coefficients from the I/O part and INFORUM, the output coefficients from INSIDE, and the total outputs. From this information we can organize the economic changes so that they are functionally related to the changing composition of the automobile. The advantage of

Figure III: Partial Flow Analysis of Material Inputs to the Automobile Industry
by Platform*

*Flow values in the circles represent the total amount of material in short tons.

TABLE 13

[illegible]

[illegible]	Net Probable Tax % Change	Nuclear Shortfall Electricity % Change	Nuclear Shortfall Electricity % Change
Consumer Purchases			
60. Petroleum Refining	-24.51	-25.27	-25.27
TOTAL OUTPUT			
11. Iron Ores	- 5.06	-27.39	-30.27
12. Copper Ore	- 3.38	- 3.77	- 3.46
13. Other Non-Ferrous Ores	4.56	12.38	2.39
14. Coal Mining	- 1.94	- 2.77	- 2.70
15. Crude Petroleum, Natural Gas	3.38	3.59	3.47
42. Plastic Materials & Resins	1.41	1.38	3.42
60. Petroleum Refining	-24.51	-25.69	-30.79
78. M.,c. Plastic Products	2.69	2.77	6.63
81. Steel	- 6.56	-42.78	-30.97
84. Copper	- 3.38	- 3.73	- 3.42
87. Aluminum	6.95	20.7	5.88
97. Metal Stampings	- 3.69	- 3.66	- 3.66
154. Motor Transportation	- 2.06	- 2.29	- 2.26
156. Pipelines	- 2.71	- 2.86	- 2.66
160. Electric Utilities	- 1.14	- .34	- .78
161. Natural Gas	- 1.23	- .37	- .25

[redacted]

[redacted]

[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
14.10	Surface Coal Mining	- 1.54	- 2.37	- 2.78
14.11	Underground Coal Mining	- 1.54	- 2.37	- 2.78
15.1	Industrial Collection of Natural Gas	2.38	3.59	3.47
15.3	Crude Oil Domestic Production	2.38	3.59	3.47
15.4	Domestic Natural Gas Production	2.38	3.59	3.47
65.15	Tetraethyl Lead	-10.45	-20.31	-20.31
65.22	Hydrofluoric Acid	4.47	10.82	3.39

[illegible]

[illegible]

-[illegible]-

[illegible]	Max Probable Dir % Change	Maximum Credible Alarmism Dir % Change	Maximum Credible Rhetoric Dir % Change
Subject Subsectors (cont'd)			
61.7 Hydrochloric Acid	- 1.77	- 2.73	- 1.61
61.13 Sodium Metal	-18.45	-20.38	-20.38
61.16 Ethylene/Propylene	.63	.46	1.71
62.1 Polyvinyl Chloride	.17	.11	.56
62.2 Phenolic Resins	1.78	1.73	1.62
62.3 Nylon	- .07	- .05	- .07
62.4 Polystyrene	1.41	1.34	1.43
69.4 Crude Oil Refining	-10.07	-10.93	-10.98
69.6 Gasoline Production	-18.45	-20.38	-20.31
69.33-			
37 Refineries	-10.07	-10.93	-10.99
81.5 Lime	- 7.97	- 3.66	- 3.31
82.4 Iron Foundry Production	- 5.65	-12.79	-10.97
83.6 Ferroalloy Production	- 5.65	-12.79	-10.97
83.7 Coal Tons Coking	- 5.65	-12.79	-10.97
83.8 Steel Foundries	- 5.65	-12.79	-10.97
84.1 Copper	- 3.36	- 3.73	- 3.48
87.1 Bauxite Refining C	-10.65	455.77	+ 7.35
89A Manganese	- 4.77	- 5.96	- 5.38
1601 Electricity by Coal	- .22	- .37	- .27
1602 Electricity by Oil	- .22	- .37	- .27
1603 Electricity by Gas	- .22	- .37	- .27

this approach is that it provides a casual understanding of why parts of the economy are changing. For example, water transportation is reduced by 8.29%. This reduction is almost entirely attributed to the reduced iron ore required for steel production. The other advantage of this type of flow analysis is that it provides insight into how dependent one industry's output is upon another. For example, sodium metal is entirely dependent upon gasoline sales whereas coal production is only partially dependent upon steel output. Electricity is highly diversified so that changes in steel and aluminum production causes only a small decrease in the electricity production.

Two other major economic conclusions can be derived from this integrated analysis which were not evident prior to the running of SEAS:

(1) Even though plastic sales to automobiles in the maximum plastics scenario increases 260% per car in 1985 over the base scenario, overall plastics output is only 3.43% greater than the base scenario in 1985. The model thus indicates that the sale of plastics to other industries is growing so rapidly as to overwhelm the increasing sales of plastics to automobiles.

(2) In the maximum aluminum car scenario (3), 4.4×10^{15} BTUs of energy are saved over the base case scenario (1). The SEAS models, in conjunction with other sources, provide an estimate on how this savings is achieved.[1] 81.6% (3.6×10^{15} BTUs) of this savings is achieved as a result of reduced gasoline consumption, resulting from a higher miles per gallon. 6.3% ($.28 \times 10^{15}$ BTUs) is attributable to savings in automobile production, and 12.1% ($.537 \times 10^{15}$ BTUs) from general reductions in the economy. The overall savings to the economy is 4%. The SEAS scenario (1) run assumed a 1985 normal energy demand requirement of

111,150 x 10^{15} BTUs. The SEAS base case scenario (1) assumes an energy demand which is consistent with FEA Project Independence 1985 forecast of 109.5 BTUs (in their scenario of $7 per barrel of oil without conservation policies).[1] The major difference is that SEAS in the scenario (1) run assumes that the automobile composition remains at a constant 1971 level while FEA projects a lighter car resulting in a smaller forecast for transportation uses of energy. In the maximum aluminum car scenario, the BTU forecast for the economy was 106.7 x 10^{15} BTU. This is about 4% lower than the base case scenario and about 2.7% lower than the FEA projection. Table J4 presents the results discussed above.

1. Pollution Analysis (SEAS RESGEN Module)

Economic activity results in the generation of pollutants which may be discharged into the environment. The SEAS RESGEN model has developed pollution coefficients which translates the level of economic activity into pollution loadings. These pollution coefficients are composed of two terms, the gross coefficient and the fraction of pollution which is abated. The gross coefficient is the amount of pollution output resulting from the activity if no pollution control devices are installed. The amount treated is related to the percent of industry which has installed control devices and the abatement efficiency of the devices.

The RESGEN model was run against the economic outputs of scenarios (1) and (2), the base and most probable cases. A pollution analysis was not performed for scenarios (3) and (4) because their results were similar to those of scenario (2). The pollution results are presented in Table J5 and provide gross pollution outputs and pollution outputs with abatement controls which meet EPA federal pollution standards (net pollution outputs).

1) FEA assumed that by 1985 automobiles will consume 93.7 x 10^9 gallons at $7 per barrel of oil. Scenario (1) projected that 114.0 x 10^9 gallons will be consumed by automobiles in the future and the maximum aluminum scenario (3) projected gasoline consumption of 80.7 x 10^9 gallons.

TABLE J4

COMPARISON OF MAXIMUM ALUMINUM SCENARIO WITH BASE CASE: ENERGY REQUIREMENTS FOR THE U.S. ECONOMY 1985 (10^{15} BTUs)

	Base	Max Alum[a]	Difference
Coal	19.0	19.4	0.416
Gas	23.9	23.9	0.018
Oil (nontransportation)	24.7	24.3	0.395
Oil (transportation)[a]	35.1	31.8	3.619
Nuclear	12.5	12.5	0
Other	4.8	4.8	0
	110.9	106.5	4.436
			(4.055)

[a]Energy requirements for the maximum aluminum car were obtained by multiplying the percent savings in the coal, gas and nonconsumer use of oil as projected by INFORUM times the base forecast. The savings from transportation demand were calculated directly using the SEAS projection of vehicle miles travelled and miles per gallon figures for both scenarios.

The pollutants examined in this study are:

Air

Particulates
Sulfur Dioxide
Nitrogen Oxide
Hydrocarbons
Carbon Monoxide.

Water

Biological Oxygen Demand
Chemical Oxygen Demand
Suspended Solids
Phenols, oils and greases.

The primary conclusion is that pollution generated from the entire economy in the most probable case scenario (2) is reduced slightly from the base case. Gross emissions are reduced by .71% for particulates, 2.8% for sulphur oxides, 7.3% for hydrocarbons, 3.7% for carbon monoxide, 6.4% for phenols, and 1.9% for oil and greases. The remaining pollutants are affected by less than 1%. Net particulates are also reduced by 1.22%, sulphur oxide emissions by 1.7%, hydrocarbons by 1.4%, phenols by 4.0%, oil/greases by 9.5% and the remaining by less than 1%.

For particulate generation, the largest change occurs with the steel fabrication and sintering processes. In these activities, particulate emissions are hard to control and reduced steel production results in a 10% or a 16,000 ton reduction in particulate emission. A 4,800 ton reduction in particulate emission occurs from the other steel processes. The increases in aluminum production in the most probable case (9% in output) accounts for only an increase of 772 tons of particulates. This seems to indicate that materials which are being substituted are not as significant polluters as those they are replacing.

Changes in sulphur oxide emissions result almost entirely from refineries with catalytic crackers. The reduced gasoline requirements

of the most probable car scenario results in a 10% or 47,000 tons reduction in sulphur oxide emissions from refineries. Reductions in hydrocarbon and carbon monoxide emissions are also the result of reduced petroleum output.

Hydrocarbon emissions from gasoline storage are reduced by 18% or 57,600 tons. Gross carbon monoxide emissions from refineries with catalytic crackers are reduced by 10% or 1,360 thousand tons, but because of stringent EPA regulation, net emissions are only reduced by 5,540 tons.

For water pollution, only phenols and oil/greases experience significant decreases, both resulting from less crude oil flowing through petroleum refineries and reduced steel production. They experience reductions of 10% for various aspects of petroleum refining and steel production.

Though the national impact is minimal, there is a reduction in pollutants due to decreased petroleum refining and iron and steel production. Communities with petroleum refining and steel plants will notice a degree of reduced pollution. However, if EPA regulations are enforced by 1985, the reduced emissions resulting from these lower production levels are unlikely to have a significant impact even on a local level. The reduction from pollution controls outweighs the reductions resulting from material substitution.

TABLE 8

[redacted]

-385-

[redacted]	Base Case		Mod. Project's Case	
Particulates	Gross	Net	Gross	Net
34. Coal Mining				
35. Coal Cleaned and Dried	370,700	1610	377,700	1,639
05. Petroleum Refining				
31. Refiner w/ Catalytic Crack	338,200	2,300	345,400	2,350
05. Steel				
6. Ferroalloy Production	1,657,000	165,700	1,687,000	168,700
8. Steel Foundries	485,000	4,700	492,500	8,850
30. Open Hearth Furnace-Integr.	35,000	406.4	35,000	367.1
31. Basic Oxygen Furnace	77,500	2,327	79,000	2,370
32. Electric Arc Furnace	2,370,000	23,700	2,400,000	24,000
33. Cupola Furnace	256,000	2,560	260,000	2,600
	96,000	1,940	97,000	1,970
06. Copper				
31. Secondary Copper	5,700,000	0	5,700,000	0
34. Smelting w/ Reactor	307,000	2,000	312,000	1,960
35. Smelting w/o Reactor	216,000	1,274	220,000	1,274
07. Aluminum				
31. Secondary Aluminum	25,000	5,400	25,000	5,000
34. Prebaked Anode	227,000	4,540	230,000	4,600
35. Horizontal Soderberg	26,000	598.1	32,000	640
36. Vertical Soderberg	12,000	552.0	13,000	270
TOTAL	156,000,000	3,000,000	158,000,000	3,070,000
% Difference			Gross % Diff.	Net % Diff.
			.77%	1.33%

	Base Case		Most Probable Case	
	Gross	Net	Gross	Net
I. Sulfur Scrubbers				
14. Coal Mining				
34. Coal-Synthetic Fuels	[illegible]	[illegible]	[illegible]	[illegible]
40. Petroleum Refining				
30. Refiner w/ Catalytic Crack	[illegible]	[illegible]	[illegible]	[illegible]
41. Steel				
35. Byproduct Coking	[illegible]	[illegible]	[illegible]	[illegible]
84. Copper				
34. Smelting w/ Roaster	[illegible]	[illegible]	[illegible]	[illegible]
35. Smelting w/o Roaster	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]
% Difference			Gross: % Diff. 2.6%	Net: % Diff. 1.7%
II. Nitrogen Oxides				
40. Petroleum Refining				
30. Refiner w/ Catalytic Cracking	[illegible]	[illegible]	[illegible]	[illegible]
41. Steel				
35. Byproduct Coking	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]
% Difference			Gross: % Diff. .4%	Net: % Diff. .3%

	Base Case		Most Probable Case	
4. Hydrocarbons	Gross	Net	Gross	Net
49. Petroleum Refining				
30. Refiner w/ Catalytic Cracking	[illegible]	[illegible]	[illegible]	[illegible]
4. Crude Oil Refining	[illegible]	[illegible]	[illegible]	[illegible]
6. Gasoline Production	[illegible]	[illegible]	[illegible]	[illegible]
61. Steel				
39. Byproduct Coking	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]
% Difference			Gross % Diff. 7.3%	Net % Diff. 1.4%
5. Carbon Monoxide				
49. Petroleum Refining				
30. Refiner w/ Catalytic Cracking	[illegible]	[illegible]	[illegible]	[illegible]
61. Steel				
33. Open-Hs Furnace	[illegible]	[illegible]	[illegible]	[illegible]
34. Elec Arc-Iron Foundry Production	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]
% Difference			Gross % Diff. 3.7%	Net % Diff. .7%

[illegible]

	Base Case		Max. Available Case	
	Gross	Net	Gross	Net
1. Petrochemical Dragon Depart.				
60. Industrial Chemicals				
13. Tetraethyl Lead	34,480	75.69	74,563	61.88
61. Misc. Chemical Products				
14. Ethylene/Propylene	4,675	451.7	9,972	634.3
62. Plastic Materials & Resins	836,435	47,855	940,239	42,413
63. Petroleum Refining				
32. Topping Plants	780.1	780.7	773.8	788.6
34. Cracking	34,139	1,329	28,779	1,295
35. Petrochemical	30,000	651	27,300	585.9
36. Lube Oil	61,842	1,782	55,726	1,603
37. Integrated	23,560	982.4	21,576	913
65. Steel				
39. Byproduct Coking	58,540	2,303	62,373	2,324
TOTAL	27,000,000	1,335,000	27,027,333	1,333,943
% Difference			Gross % Diff. .08	Net % Diff. .79
1A. Chemical Dragon Depart.				
60. Industrial Chemicals				
13. Tetraethyl Lead	140.2	65.43	114.3	68.75
61. Misc. Chemical Products				
14. Ethylene/Propylene	25,700	74,900	25,600	15,000
62. Plastic Materials & Resins	1,334,000	172,456	1,353,300	175,000

| | | |

J.4 Solid Waste and Recycling Analysis (SEAS SW/R Module)

Solid waste is generated from the disposal of consumer and industrial waste. The SEAS SOLID WASTE/RECYCLING (SW/R) model provides estimates of the quantity and composition of solid waste generated and levels of recycling. The 1985 recycling levels in the model assume that government and industry encourage recycling.

The SW/R model was run against the economic outputs of scenarios (1) and (2), base and most probable case of automobile materials composition. An analysis of scenarios (3) and (4), maximum aluminum and maximum plastic cases, was not performed because they were found to have results similar to the most probable case.

Estimates of solid waste are based on industrial production statistics, which measure the amount of material produced for fabrication into finished products. The SW/R model makes projections of materials which enter the economy. The direct impact of the substitutions is indicated by the output of ferrous metals and aluminum, the materials most affected by the substitutions. As can be seen in Table J6, ferrous metals experience moderate growth rates of 2.5% and 1.8% in the respective cases; while aluminum grows somewhat faster at 4.7% and 5.5%. Even though the amount of iron and steel going into the automobile declines substantially over time in the projected most probable case, iron and steel production moderately increases throughout the period. It experiences a growth rate of .7% less than that of the base case, due primarily to increased demand by other nonautomotive industries and a projected increase in the total output of the motor vehicle industry. These projections agree essentially with those presented by W. L. Henn.[1]

1) W.L. Henn, "Future Scrap Requirements and Prospects for Automotive Recycling," Appendix F. The projection used for this analysis was 200 million tons, which included home scrap, which is approximately 35% of total raw iron and steel generated. The SW/R model projected 154 and 139 million tons for each of the cases which would translate into 237 and 214 million tons including home scrap.

TABLE J6

MATERIAL REPORT[a]
(Thousand Tons)

	Ferrous Metals		Aluminum	
	Base Case	Most Probable Case	Base Case	Most Probable Case
1975	116,480	113,768	5,629	5,636
1976	126,180	122,022	6,256	6,327
1977	133,144	127,629	6,805	6,951
1978	134,819	127,665	7,104	7,330
1979	141,429	132,513	7,628	7,949
1980	148,217	137,310	8,166	8,954
1981	149,130	137,482	8,413	8,916
1982	149,851	137,411	8,634	9,219
1983	150,954	137,733	6,901	9,570
1984	157,249	138,271	9,174	9,930
1985	153,884	139,045	9,466	10,312

[a]Total material shipped for fabrication into finished products.

The implications of the changes in production for scrap availability can be seen in Figures J2 and J3 where scrap made available from the two materials is plotted through 1995. Substantial increases in total available obsolete scrap, are indicated for both cases. Aluminum scrap availability exhibits a proportionately greater increase than ferrous metals. However, the impact on solid waste is not felt until the late 1980's and early 1990's because of the time lag between production and actual disposal of the material into the waste system.

There is approximately a 10% difference in total available iron and steel and aluminum scrap in each case by 1995. However, there is a significant impact on the availability of scrap derived from automobiles, with a 40% decline in iron and steel scrap from the base case and a greater than twofold increase in aluminum. The change in material requirements for automobiles does not have a significant impact on the economy as a whole as discussed in other sections of this paper.

The critical question posed by the substitution of ferrous metals is whether or not a sufficient quantity of scrap will be available for the requirements of the iron and steel industry. Automobiles have traditionally supplied a major portion of obsolete scrap to be recycled as discussed by W. L. Henn in Appendix F, "Future Scrap Requirements and Prospects for Automotive Recycling" and as projected in the SW/R model. The major constraints upon the use of nonautomotive sources of ferrous scrap have been economic, reflected in their scattered locations, high processing costs, and problems of contamination. Automobile scrap, available in units capable of being bundled or shredded and often brought to centralized disposal sites, has provided a good supply of scrap for the iron and steel industry. According to W. L. Henn, the annual retirement of automobiles will not be sufficient by the mid-1980's to provide the scrap in the same proportion to that which has been supplied in the past. This analysis is based on projected scrap requirements of the steel industry and capacity of the shredder industry assuming its present rate of growth.

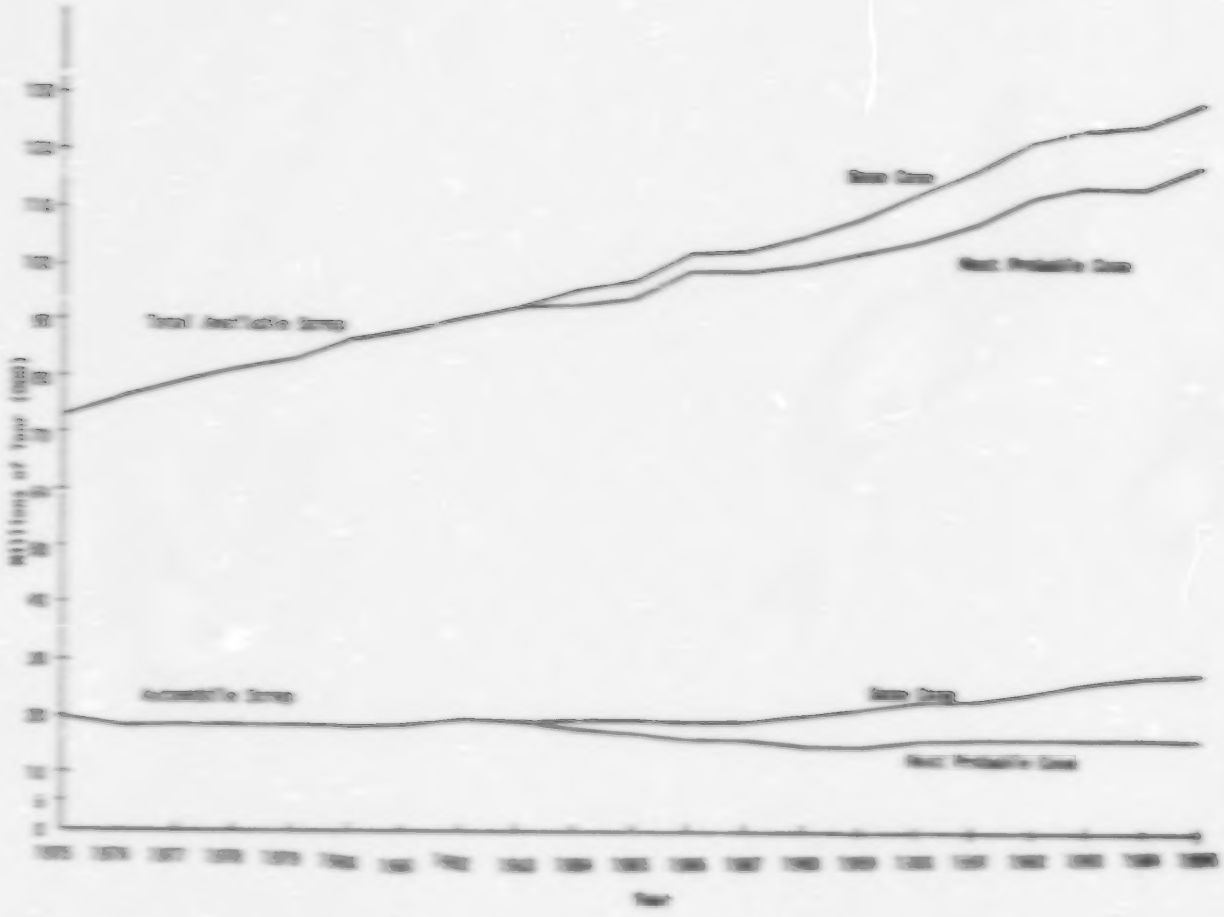

Figure 22: Projected Vehicle Ferrous Scrap, 1975-1995 (millions of tons)

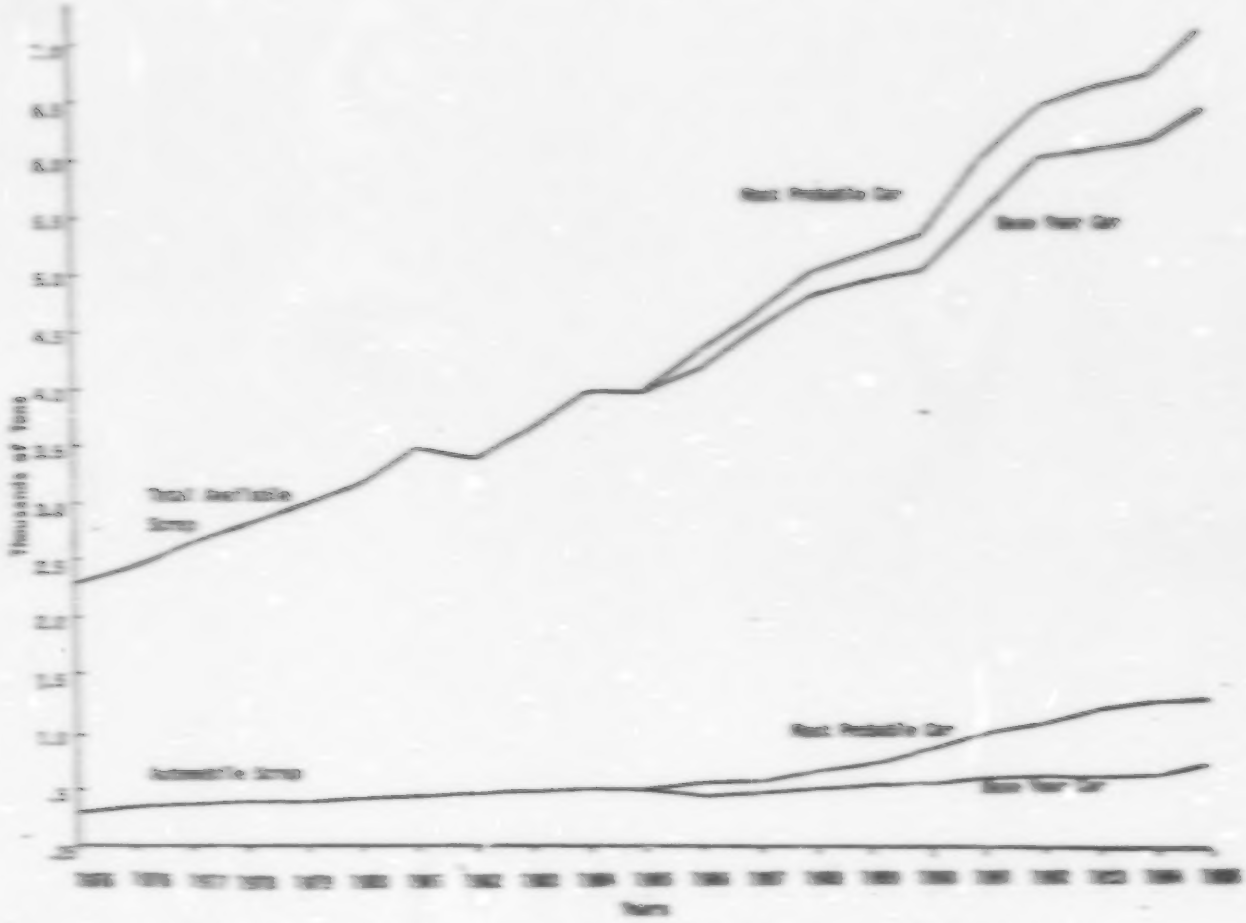

Figure 2b: Projected Available Plankton Score, 1975-1995 [Thousands of Tons]

Given this conclusion, the question arises whether or not other portions of the economy generate sufficient quantities of ferrous scrap capable of being recycled and thus fill the gap created by increased shredder capacity and demand for scrap by the iron and steel industry.

The SW/R model provides estimates of recycled material and assumes increases in the rate of recycling for various product categories. Based on the projected iron and steel furnace scrap requirements presented by W.L. Henn, total purchased scrap requirements would be 64.7 and 58.4 million tons in 1985 for each case as presented in Table J8. The SW/R model estimates that 58.6 and 54.3 million tons will be recycled in that year. Thus, a shortfall of 6.1 and 4.1 million tons is projected in each respective case assuming no scrap exports. With exports the projected shortfall will be greater. It is interesting to note that the base case incurs a greater shortfall than the most probable because of projected higher scrap requirements for steel making. This projection agrees with the conclusion reached in Appendix F that a ferrous scrap shortage is likely if recycling of nonautomotive products is not encouraged. Even though the SW/R model assumes some increases in recycling of nonautomotive products based on an optimistic industry projection, a shortfall occurs. Consumer durables (appliances) and industrial machinery may be considered as potential sources of concentrated scrap which could be economically recycled beyond the projections made in the SW/R model given a rise in scrap prices and assuming increased shredder capacity. Potential scrap from these sources is presented in Table J8 and is more than sufficient to cover the projected gap in scrap demand. This value does not include the backlog of presently discarded nonautomotive products.

The major conclusion of this analysis is that the ferrous scrap situation will be tight. Given increasing shredder capcity, scrap dealers may be driven into utilizing nonautomotive discarded products for sources of scrap. This situation would help to alleviate our national solid waste problem.

TABLE 37
RECYCLING REPORT[a]
(Thousand Tons)

	Ferrous Metals		Aluminum	
	Base Case	Most Probable Case	Base Case	Most Probable Case
1975	39396(.336)	39879(.341)	1451(.208)	1452(.208)
1976	42473(.337)	41725(.342)	1640(.262)	1651(.261)
1977	44067(.337)	43694(.344)	1816(.271)	1839(.269)
1978	46276(.343)	44988(.352)	1978(.284)	1914(.261)
1979	48482(.343)	46871(.354)	2029(.273)	2129(.268)
1980	50804(.343)	48811(.356)	2309(.283)	2376(.276)
1981	52235(.350)	50041(.364)	2519(.290)	2595(.291)
1982	53800(.359)	51318(.373)	2493(.284)	2546(.276)
1983	55408(.366)	53550(.387)	2777(.305)	2826(.295)
1984	57050(.375)	53550(.387)	2857(.311)	2983(.301)
1985	58578(.381)	54330(.391)	2949(.312)	3102(.301)

[a]Total amount of scrap recycled prompt and obsolete, and fraction of total material demand derived from recycled scrap.

TABLE 38

IRON AND STEEL SCRAP REQUIREMENTS[a]

-1985-

	Base Case	Most Probable Case
Iron and Steel Output	157,884	139,045
Home Scrap @ 35% of Total Production	82,861	74,870
Total Iron and Steel Production	236,045	213,915
Total Scrap Requirements	147,600	133,253
Home Scrap	82,861	74,870
Purchased Scrap Requirements	64,739	58,383
Prompt	26,320	23,782
Obsolete	38,419	34,601
Total Scrap Recycled	32,256	30,548
Shortfall	6,163	4,053
Potential Scrap from Household Durables and Machinery	8,846	8,846
Total Available Obsolete Scrap	95,845	91,820

[a]Scrap requirements for 1985 were computed based on the following projections for iron and steel furnaces:

	Production Level (%)	Scrap Requirements (%)
Basic Oxygen	55.9	33
Open Hearth	6.2	50
Electric Arc	26.0	98
Foundry	11.9	93

plus an additional estimate for the requirements of blast and miscellaneous furnaces. These levels were derived from estimates presented in Appendix F and in Battelle's Identification of Opportunities for Increased Recycling of Ferrous Solid Waste, EPA, 1977. Other estimates were based on results in the Solid Waste/Recycling Model.

The SEAS model is a broad based national model and was not designed to take into consideration the peculiarity of the steel industry. Possible changes in the steel industry such as a greater shift to continuous casting, foreign imports of scrap or other major material substitutions, are not considered. Thus, the result, though highly significant, is tentative.